

High Resolution Diagnostics of a Linear Shaped Charge Jet

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The linear shaped charge is designed to produce a knife blade-like flat jet, which will perforate and sever one side of a modestly hard target from the other. This charge is approximately plane wave initiated and used a water pipe quality circular copper liner. To establish the quality of this jet we report about an experiment using several of the Lawrence Livermore National Laboratory high-resolution diagnostics previously published in this meeting [1]. Image converter tube camera stereo image pairs were obtained early in the jet formation process. Individual IC images were taken just after the perforation of a thin steel plate. These pictures are augmented with 70 mm format rotating mirror framing images, orthogonal 450 KeV flash radiograph pairs, and arrival time switches (velocity traps) positioned along the length of the jet edge. We have confirmed that linear shaped charges are subject to the same need for high quality copper as any other metal jetting device.

INTRODUCTION

Linear shaped charge jets have not been examined in the same detail as axisymmetric jetting devices. That is probably due the limited penetration and stand-off requirements usually applied to such devices. We have decided to examine, in fine detail, the behavior of a plane wave initiated linear shaped charge, which uses a water pipe quality circular copper liner. To this end, the LLNL Site 300 (explosive test site) diagnostic suite was applied. Eight individual frames of the, now well known "Image Converter (IC) Camera" were taken at various stations and times during the jet evolution using the fast "Laser Illuminator" for freeze frame precision. Two color 70 mm rotating mirror framing records were obtained under

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electrical flash lamp lighting. Five frames of orthogonal 450 KeV radiographs were attempted. However, one frame was ruined by the explosive shock wave.

EXPERIMENTAL SETUP

The edge of the jet was arranged perpendicular to the ground, while the jet motion was parallel to the ground. The charge was about 7 liner widths long. Two steel plates were positioned at about 4 liner widths and 40 liner widths from the charge face to act as targets. A series of velocity traps were located adjacent and in front of each plate. These traps used pairs PVF piezo-electric film-strips stationed at 10 equally spaced vertical positions. Each pair was spaced apart in the direction of jet motion by a layer of plastic foam. The signals from each of the 40 PVF strips were recorded on individual 5 ns digitizers. White foam board was used to form lighted regions near each station of optical recording.

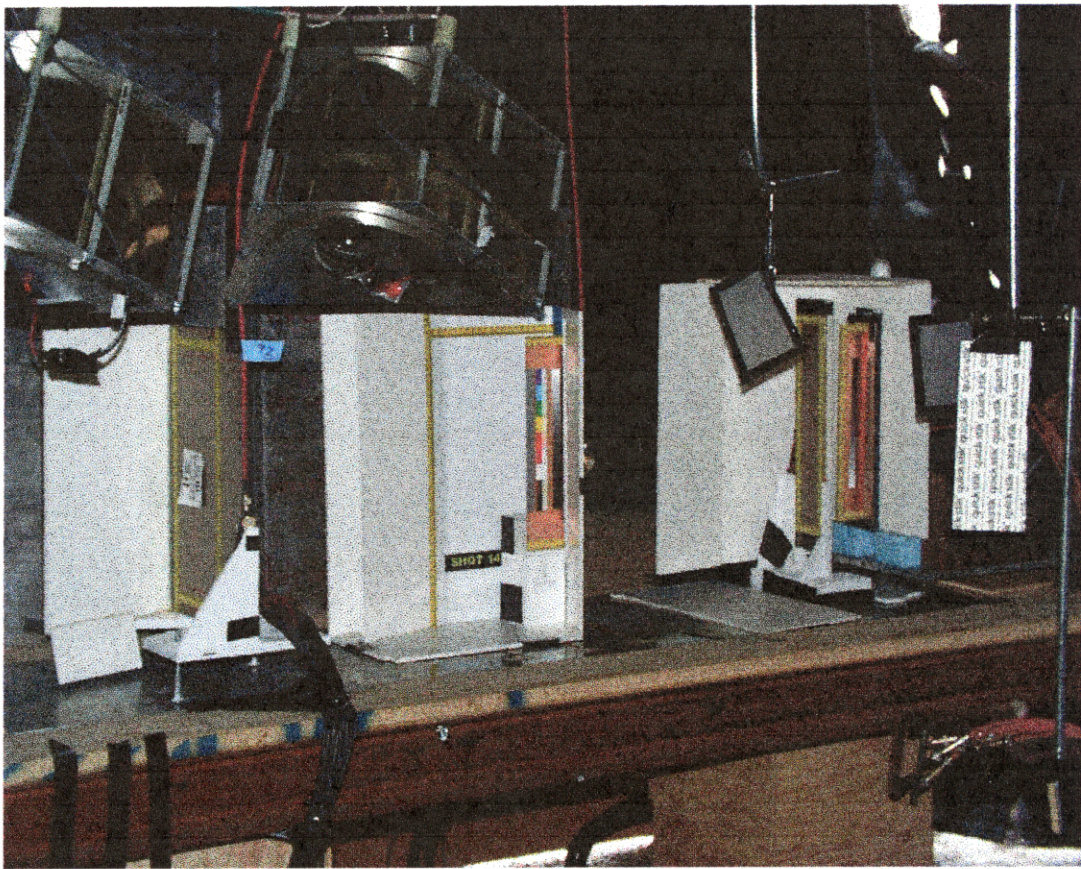


Figure 1. Photograph of table setup for an optical and radiographic dry run.

In figure 1, the shaped charge is on the right (with the blue base). The shot has a plane piece of copper positioned as a mock of the jet (edges have yellow tape) for focussing purposes. The first target plate is immediately to the left of the shot (shown with yellow tape), while the second target plate is to the far left of the photograph. Located in the space between the two target plates is a region

surrounded by foam board, where one of the two 121 rotating mirror framing cameras is focussed. A second copper focus mock of the jet is located at this position. The second 121 is looking at the region to the left of the second target plate. Shown in the upper left corner of the photograph are the two electric flash lamps. Use of these lamps is made necessary by the several radiographic cassettes, which could not be sufficiently protected from standard explosive candles. On either side of the shot can be seen two diffuser plates used to spread the light from the laser illuminator beams. Standing vertical behind the shot line are two large square radiographic cassettes used to record the plane profile of the jet when it is positioned in mid-flight and again when it has just passed through the second steel target. Beneath the shot table and extending the entire length of the shot line to just beyond the second target, is a single radiographic cassette. Three x-ray heads produced three separate images on this single piece of film. So a total of five x-ray pulses from five different heads are used. These produce a) an orthogonal pair of radiographs of the mid-plane position, b) an orthogonal pair of radiographs at the second target position, and c) a single overhead image, edge-on, of the jet in its formation period.

Not visible in figure 1 are the two velocity trap arrays. The foam boards and target plates hide them. Figure 2 shows one of these traps.

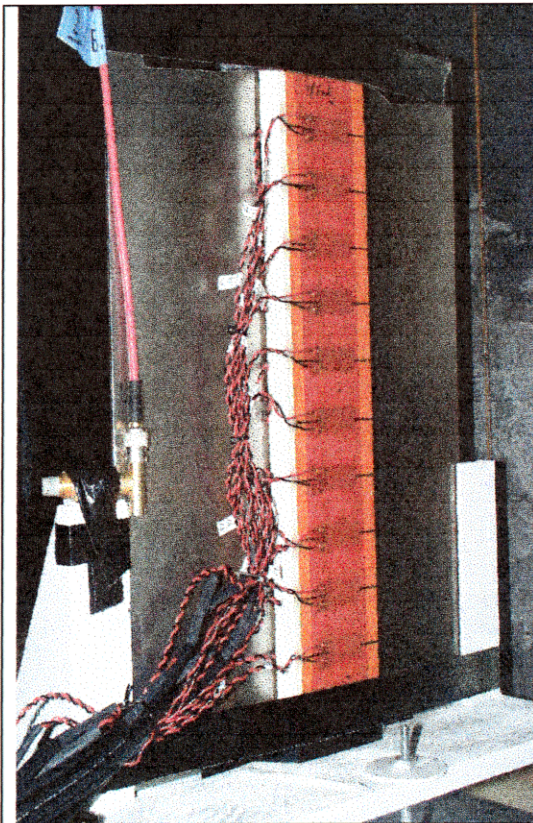


Figure 2. A piezo-electric velocity trap located in front of one of the target plates. Visible are the individual PVF strips covered by Kapton tape.

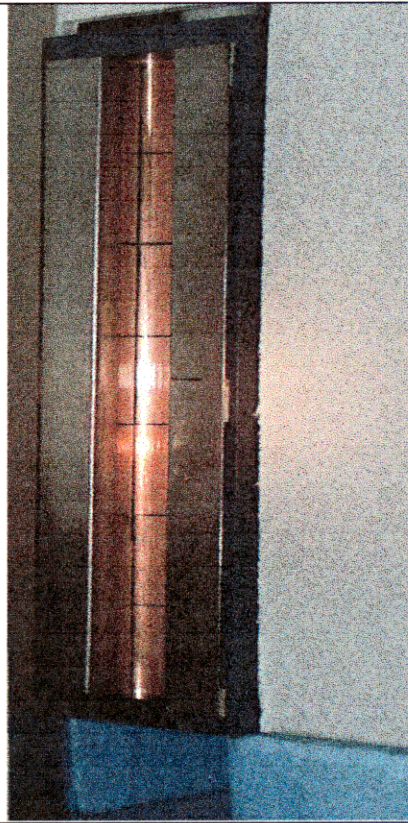


Figure 3. The face of the shot is shown ready to fire. A steel smoke shield is placed to help direct leaking explosive smoke away from the jet.

Figure 3 is photograph of the face of the shot showing the circular copper liner and the steel smoke shield positioned to deflect the smoke away from the jet formation region. The shield is necessary to keep the smoke from occluding the IC camera view of the jet.

RESULTS

Only a few of the diagnostic measurements were unsuccessful. The radiograph of the formation region was damaged by the shock wave and the second velocity trap failed to report. No amount of analysis has been able to restore the X ray image. Further analysis may, on the other hand, prove to regain the lost trap signals. Each of the eight IC camera images was returned and seven of them are shown below. Figures 4a and 4b are the stereo pair taken when the jet reached 0.7 of a charge width from the charge face. Figure 4c and 4d are the stereo pair for the tip at 0.82. Evident is a very dark, bumpy, and cloudy jet jutting to the left at about a 45-degree angle between strips of very reflective copper. HE ignition irregularities can

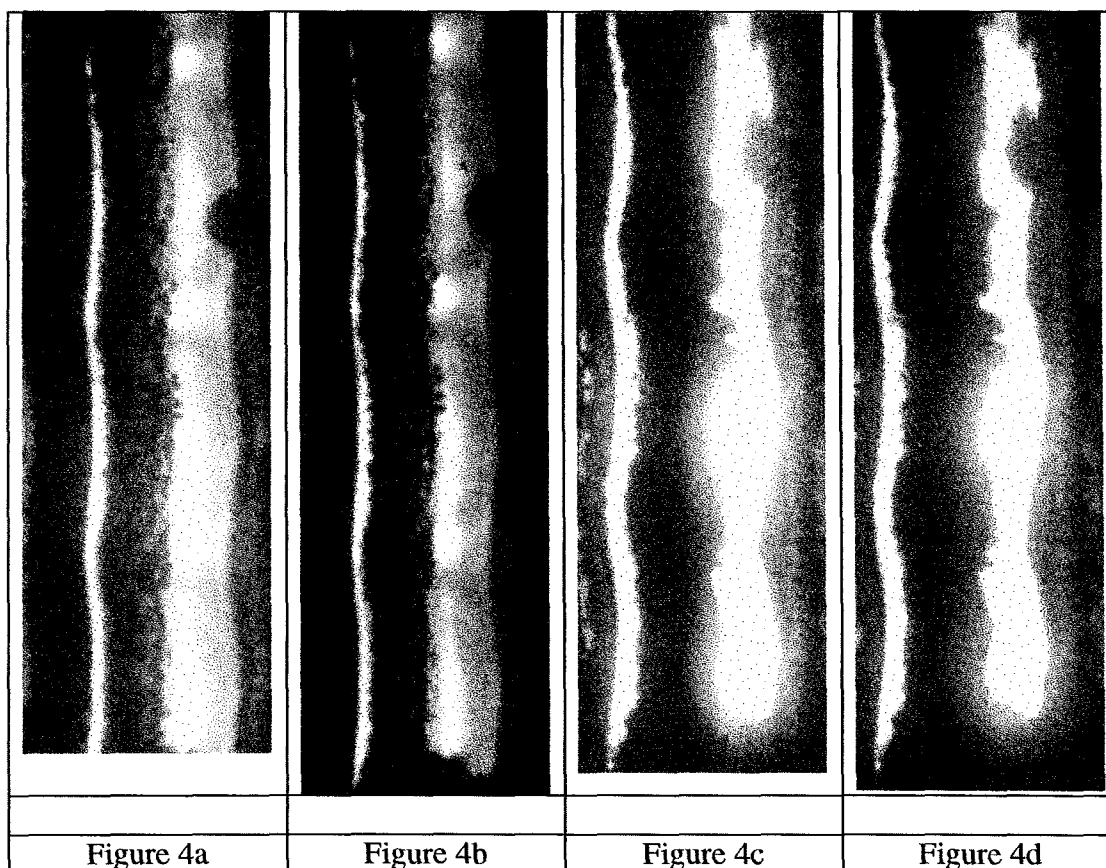


Figure 4. Two stereo image pairs 3.5 μ s apart in time are shown. Images 4a and 4b are the left and right views at an early time. The jet is the dark, granular strip in the middle. Images 4c and 4d are the same views at a slightly later time in the jet evolution. The bright area is the highly reflective copper.

be easily discerned. The next two IC camera frames are figures 5a and 5b. These are frames of the backside of the first target plate of steel, showing the jet perforation of the steel. The two images are 5 μ s apart. The jet is just beginning to break through the steel in figure 5b. The seventh and eighth IC images are of the jet progressing by the midplane at about 20 charge widths from the charge face. Image seven is at a time such that the jet has not yet appeared through the slot in the foam board and is not shown here. The eighth frame is shown as figure 5c.

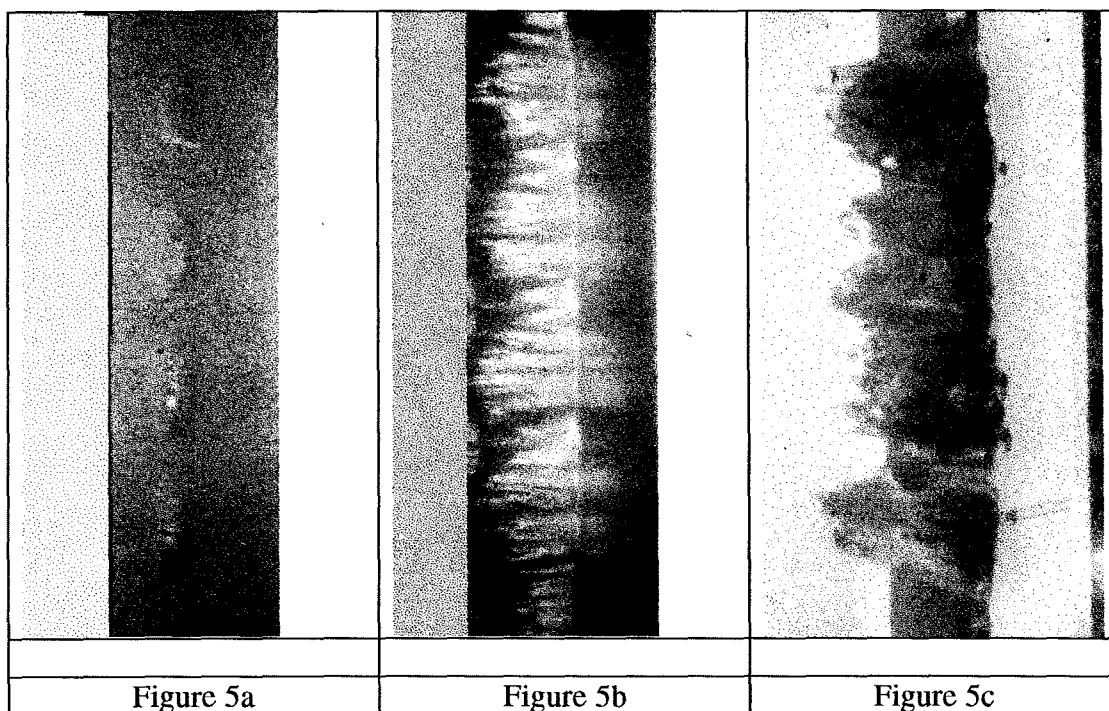


Figure 5. The IC evolution of the jet in flight. Figure 5a and 5b differ by 5 μ s and show the penetration of the first steel target plate by the jet. Figure 5c is 17 charge widths further down range, as the jet passes through a hole in the foam board.

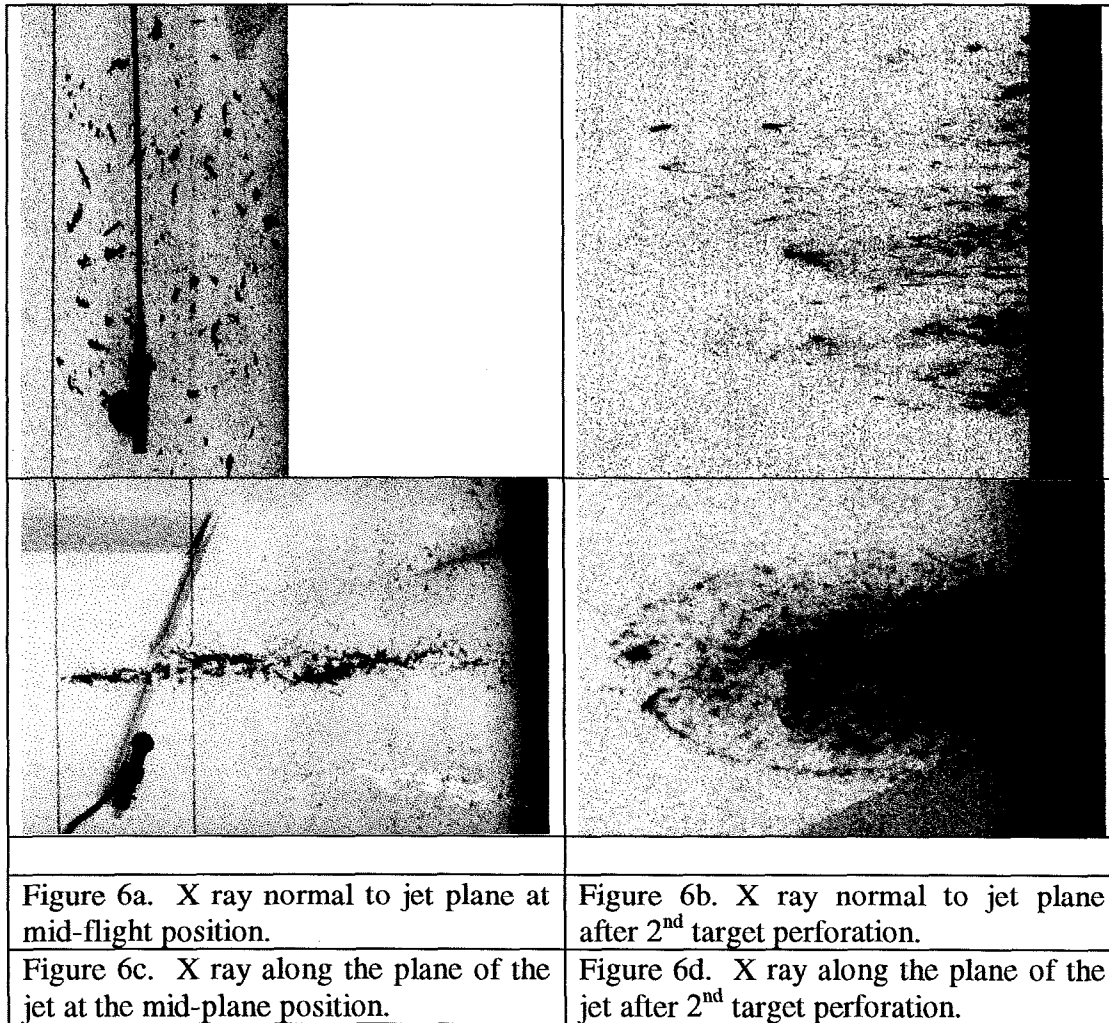
Table I lists the first velocity trap results. The jet speeds measured here are without interference of any material except the trap itself. The distance from the charge face of the first switch layer is 2.8 charge widths. The second layer is 20 mm further. The variation of the speed along the edge of the jet can be compared to the initiation irregularities in the IC stereo picture of the jet formation and the IC camera pictures of the target perforation.

Figure 6a and 6c are the orthogonal pair of X ray images taken as the jet just reached 20 charge widths down range. The two images are closely matched in size and position as the positions of the wire fiducial and the bridge wire connection suggest. The second wire fiducial of 6c is not repeated in the image in 6a. Figures 6b and 6d are the orthogonal pair of radiographs of the tip of the jet emerging from perforating the second target plate. They, also, are matched in position and

magnification. It is very clear that little is left of the large jet pieces seen in the first pair of images.

Table I. First velocity trap results.

Speed (mm/ μ s)	Position of measurement (fractions of device length).	Jet arrival time at the first layer of the trap relative to the first signal (μ s)
Did not report	0.0625	0.573
3.84	0.1875	0
4.24	0.3125	0.384
3.96	0.4375	0.028
4.06	0.5625	1.023
4.27	0.6875	0.551
3.84	0.8125	2.645
3.60	0.9375	2.699



CONCLUSIONS

The combination of optical and radiographic diagnostics (along with standard electronic measurements) can be very revealing about the performance of any shaped charge jet. That was particularly true with this jet. It is clear that the material from which the liner was made, is not of sufficiently high quality. Although the IC camera pictures show that the lighting system is not planar, it is clear that the non-planar detonation wave was not the cause of the violent and early jet breakup. The X ray images show metal pieces with quite sharp edges but fairly high coherency within the general jet envelope. This suggests the jet was almost completely formed when the brittle break-up occurred while the fact that no intact jet sheet is visible in the first X ray image confirms that break-up occurred before the jet had gone 20 charge widths.

The velocity trap and the X ray images confirm the tip of the jet to be within about 1 microsecond of simultaneous at 3 charge widths stand-off, and that the tip speed is very close to the calculated one of 4.23 mm/ μ s.

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